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SKIN FRICTION MEASUREMENT IN COMPLEX FLOWS
USING THIN OIL FILM TECHNIQUES

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The NASA Grant NAG 2-261 was initiated to support a program of research to study complex flows that occur in flight and laboratory experiments by building, testing and optimizing an on-board technique for direct measurement of surface shear stress using thin oil film techniques. The program of research has proceeded under the supervision of the NASA Ames Research Center and with further cooperation from the NASA Ames-Dryden and NASA Langley Research Centers.

In accordance with the original statement of work, the following research milestones were accomplished:

1. Design and testing of an internally mounted one-directional skin friction meter to demonstrate the feasibility of the concept.
2. Design and construction of a compact instrument capable of measuring skin friction in two directions.
3. Study of transitional and fully turbulent boundary layers over a flat plate with and without longitudinal pressure gradients utilizing the compact two-directional skin friction meter.
4. Study of the interaction between a turbulent boundary layer and a shock wave generated by a compression corner using the two-directional meter.
5. Flight qualification of the compact meter and accompanying electronic and pneumatic systems. Preliminary installation into flight test fixture.

Skin Friction Meter

The purpose of this research program was to design and implement a compact, robust, skin friction meter which utilized thin oil film methods and was capable of being operated from a remote location. Until this program, all implementations of the thin oil film technique were limited to configurations requiring optical access to a model through wind tunnel windows and thus severely constraining the type of testing environment. This program sought to expand the test facilities to encompass both wind tunnel and subsequently flight experiments.

The first phase of the research program was to construct a proof of concept model both for the feasibility of the new configuration and for the use of new optical and electronic components. The instrument utilized components such as a He-Ne gas laser, fiber optic cables, cube beamsplitter, and a CCD linear array in a self-contained device capable of measuring skin friction in one direction. The instrument was used to measure the skin friction in a turbulent boundary layer of a flat plate. The measurements were then compared with those given by a Kistler floating element gage on loan from NASA Langley. The good agreement between the two devices demonstrated the accuracy of this new implementation of the thin oil film technique. Details of this stage can be found in the attached paper, AIAA 91-0060 which was presented at the AIAA 29th Aerospace Sciences Meeting in Reno, Nevada, January 7-10, 1991.

A second instrument was then constructed incorporating the experience gained from the design of the demonstration model. Several improvements were made to further reduce the overall size of instrument and also to enhance the performance. The instrument (Figure 1) uses a CCD imaging array in order to measure both the magnitude and direction of a two-dimensional surface shear stress vector. A diode laser replaced the He-Ne gas laser helping to reduce the overall size of the instrument housing, and the model surface intrusion area was also greatly reduced from an initial value of 2 in. to the present value of 0.312 in.. The instrument is self-contained with only wires leading back to an electronic systems box and a pneumatic actuator.

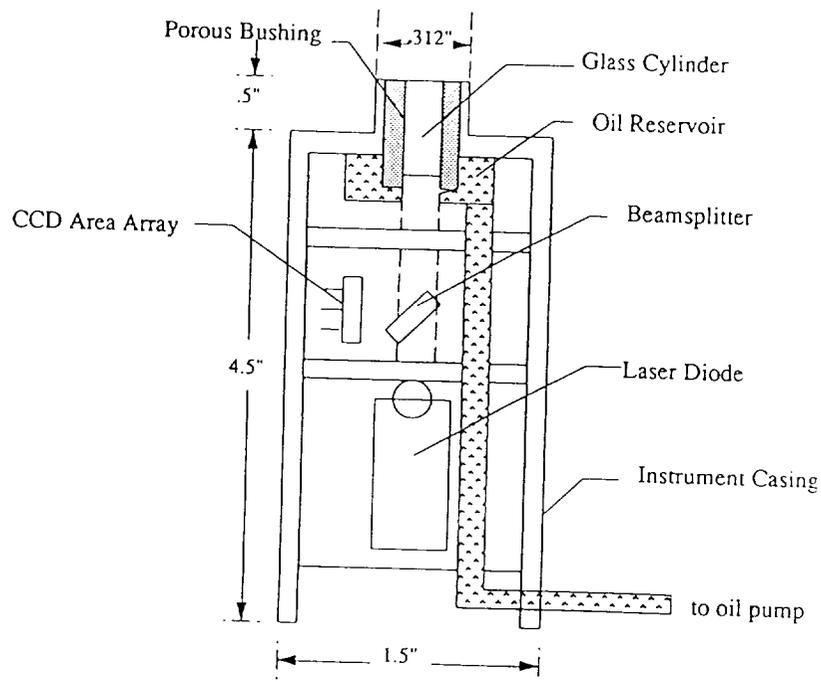


Figure 1 Compact two directional skin friction meter

Low Speed Flat Plate Experiments

As with the demonstration model, the compact two-directional instrument was used to measure the skin friction in a flat plate boundary layer. The first case with a flow with no longitudinal pressure gradient was used to verify the accuracy of the oil film gage by performing side-by-side comparisons with the Kistler floating element gage. For this condition, the floating element gage should be accurate. The two-directional compact gage was used to measure skin friction in a transition region of a boundary layer (Figure 2) and also in a fully turbulent boundary layer (Figure 3). The results showed very good agreement between the two instruments and verified the accuracy of the compact oil film gage.

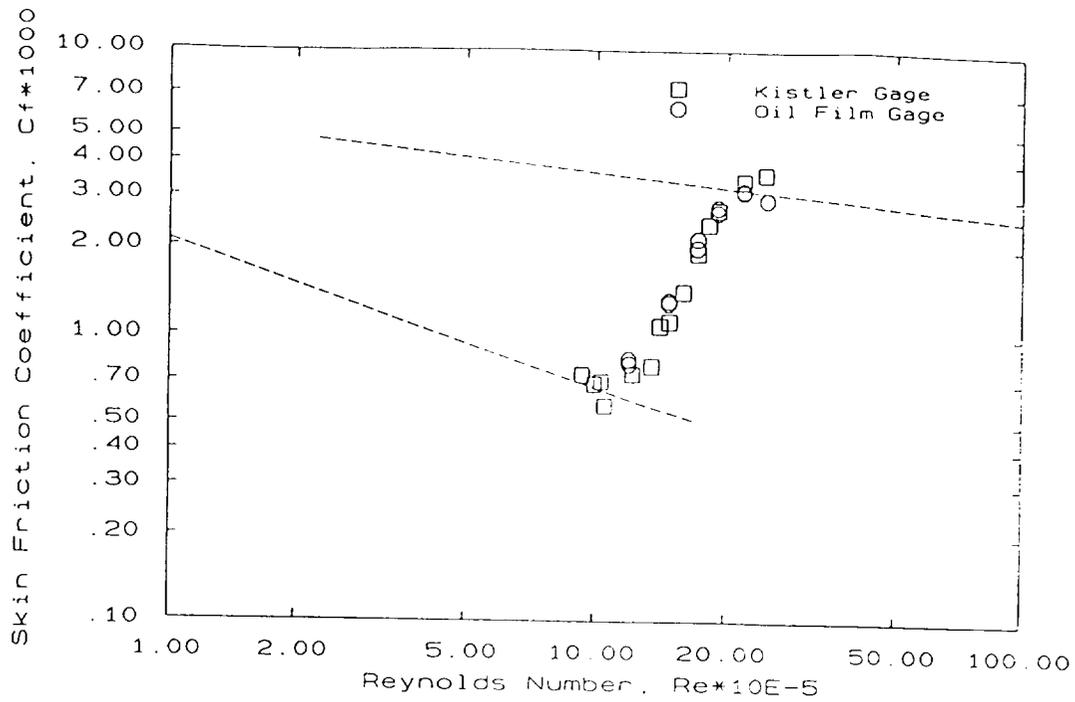


Figure 2 Comparison of zero pressure gradient skin friction measurements in a transitional boundary layer

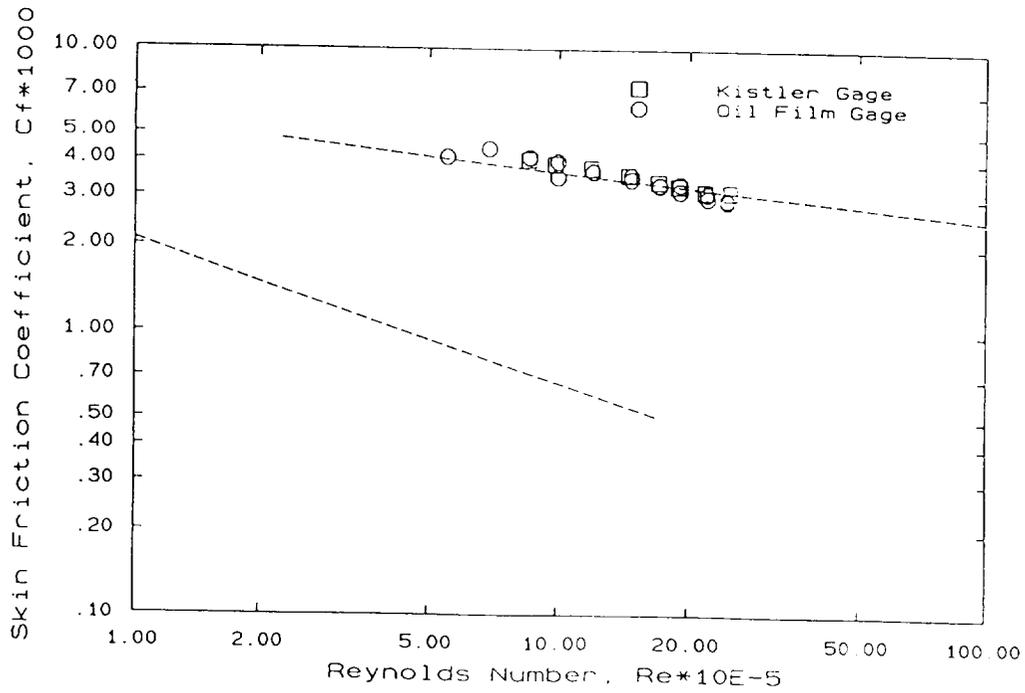


Figure 3 Comparison of zero pressure gradient skin friction measurements in a fully turbulent boundary layer

Subsequently, a longitudinal pressure gradient was created over the flat plate and measurements were taken with the Kistler floating element gage, a dual support floating element gage from NASA Langley, and the oil film gage. The oil film gage showed good agreement with the Kistler gage when a correction factor for the pressure gradient was applied to the Kistler gage readings, while temperature variations caused large scatter in the dual support gage (Figure 4). If not for these variations, the dual support gage should have been more accurate in this type of flow. These tests illustrate the usefulness of the oil film gage in increasingly complex flows such as those with a pressure gradient as the thin oil film technique is valid for a wide range of conditions and does not suffer from the inaccuracies associated with gages such as the Kistler gage. Details of this stage can also be found in the attached paper, AIAA 93-0180, which was presented at the AIAA 31st Aerospace Sciences Meeting in Reno, Nevada, January 11-14, 1993.

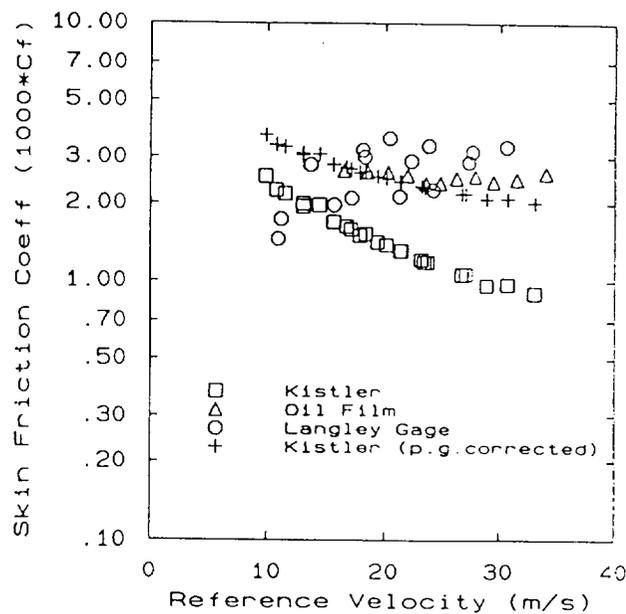


Figure 4 Skin friction measurement in favorable pressure gradient

Shock Wave-Boundary Layer Interaction

The thin oil film gage was next used to investigate the skin friction distribution in the interaction region between a turbulent boundary layer and a shock wave. In this flow the high pressure gradients and complex flow conditions rule out the use of traditional methods of skin friction measurement such as floating element gages and hot films. Previous experimenters have used Preston tubes, Stanton tubes, and thin oil film methods with wind tunnel windows. The experimental model (Figure 5) consists of a ramp to generate a compression shock wave which

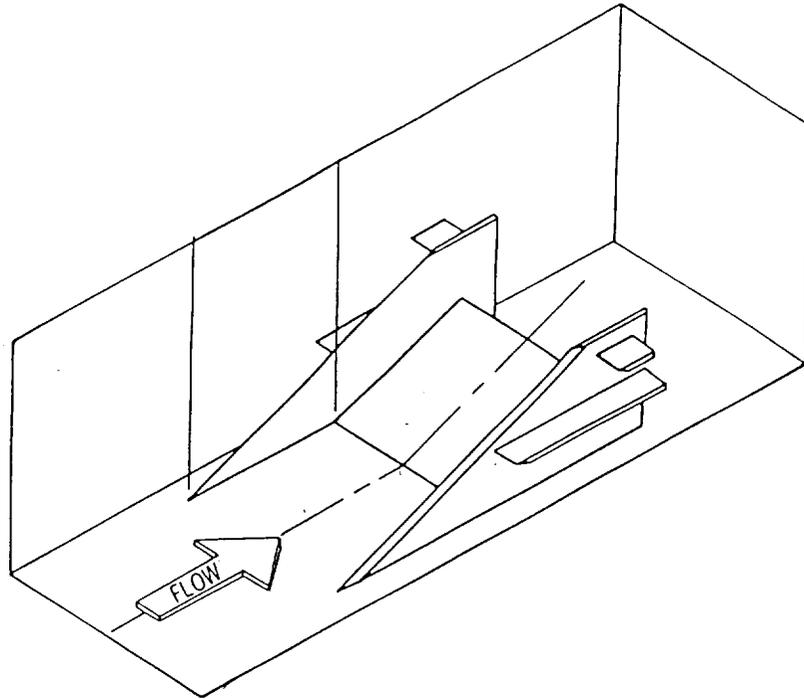


Figure 5 Shock wave-boundary layer interaction model

interacts with the tunnel wall boundary layer. Skin friction measurements are being taken throughout the interaction region with special attention paid to values at the upstream influence point. Experiments are ongoing in this phase and data will be documented at a later date in Seto (1994).

Flight Qualification and Experimentation

An important portion of this research program has been in extending thin oil film techniques to the flight environment. This was one of the driving forces in trying to make the instrument as compact and self contained as possible. The entire instrumentation package including the instrument, electronic support systems, and pneumatic actuator underwent extensive ruggedization in order to withstand a flight environment.

The entire system passed the thermal testing program from -60°C to 160°C . The system also passed the vibration testing in accordance with the appropriate NASA vibration curve with a maximum loading of 5g at 500 Hz. The system was initially installed on the F-104 Flight Test Fixture, but a problem related to the power requirement of the imaging array electronics combined

with time constraints caused the oil film gage not to be included in the initial set of flight experiments in October 1993.